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Fluid models for burning and 3D plasmas: challenging the kinetic paradigm

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We highlight recent ANU-led research in energetic particle physics and multi-relaxed region MHD. Topics include (1) the inclusion of anisotropy and flow into tokamak equilibria, stability and wave-particle interaction studies, (2) the calculation of energetic geodesic acoustic modes (EGAMs) using fluid theory, (3) the development and implementation of continuum damping in 3D, (4) the application of these tools to KSTAR, MAST and DIIID discharges, and (5) the ongoing development of multiple relaxed region MHD. A common feature of the approaches adopted is the use of fluid theory to capture the physics of energetic particles and fully 3D fields.

Our feature example is EGAMs: axisymmetric energetic particle modes found in toroidally confined plasmas resulting from the geodesic curvature of magnetic field lines. They are experimentally observed at half of the conventional GAM frequency and are localized at the core, where there is a significant fast particle population. Until recently, it was widely believed that EGAMs are driven unstable by a positive gradient of the fast particles in the velocity space. However, unlike previous studies which treat fast ions kinetically, we consider the thermal ions and fast ions as different type of fluids with a super thermal flow speed for the latter. Surprisingly, the frequency and growth rate predicted by our fluid mode agree well with the kinetic theory when the fast ion energy width is small, despite the absence of inverse Landau damping in the fluid model. This indicates the reactive nature of this instability. Further investigation reveals the similarity of our reactive EGAMs to the well-known two-stream instability. We demonstrate the consistency of reactive EGAMs with the early turn-on of EGAMs in DIII-D experiments.

We also report on progress in the modelling of fully 3D fields with Multiple Relaxed region MHD, or MRxMHD, a generalisation of Taylor's theory, in which the plasma is partitioned into a finite number of nested regions that independently undergo Taylor relaxation. The plasma regions are separated by ideal transport barriers that are also assumed to be magnetic flux surfaces. We examine the relationship between flux surface irrationality, MRxMHD stability, and tearing mode stability, as well as report on extensions of MRxMHD to include field-aligned and toroidal flow, and pressure anisotropy.

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